COLORED STONES
ASSIGNMENT 2
THE STRUCTURE AND FORMS OF GEMSTONES
IDENTIFICATION, PRODUCTION, MARKETING, BUYING

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I. INTRODUCTION

When new material is introduced in later assignments, you will have had a background for it in previous assignments. In this one, however, you will be confronted with a wealth of information for which you have had no prior background. How gemstones are formed in nature and their structure and shapes are exceedingly important subjects about which the gemologist must have a basic understanding. This forms essential groundwork for the understanding of the relationship between the internal structure of the gemstone and its properties. This assignment, of course, is not one that needs to be memorized, but it is one in which a general understanding of basic principles is important. Most people find this subject matter fascinating, whether they have any direct application for the information or not. The study of how materials form in nature into the minerals we see and the growth of crystals are subjects that still retain many elements of mystery. Many pursue these subjects as a hobby because they find the whole field fascinating.

II. THE NATURE OF GEMSTONES.

The things we see around us may be divided into two very broad classes: ORGANIC and INORGANIC. The organic materials, of course, are included in the plant and animal kingdoms, and the inorganic materials are confined to the mineral kingdom. Among gemstones we distinguish between those resulting from the activities of plants or animals (those of organic origin) and those of inorganic origin (rocks and minerals). Those of organic origin include pearl, coral, amber and jet. All other gem substances are either minerals or other materials of inorganic origin.

III. THE NATURE OF MINERALS.

Minerals are natural inorganic products that possess a characteristic chemical composition and usually a definite crystal structure. All matter is composed of one chemical element or a combination of elements; for example, diamond is composed of carbon, a single element, whereas all other gemstones are composed of combinations of elements. Metals are usually single elements, but alloys used in jewelry are intimate mixtures of metallic elements. The various mineral species are classified according to their chemical composition and the arrangement of the atoms that comprise them. In general, if a mineral formed under reasonably favorable conditions, the atoms of the elements that make up the mineral will have arranged themselves in an orderly fashion, resulting in a definite and characteristic internal structure. This definite structure is known as a CRYSTALLINE STRUCTURE or a CRYSTAL STRUCTURE. If, on the other hand, the substance is formed rapidly, or for some other reason in a manner that did not permit the atoms to arrange themselves in an orderly fashion, the material is called AMORPHOUS (pronounced ah-MOR-fuss), meaning without form. Amber, jet, glass and opal are amorphous. The difference in internal arrangement of atoms in any single plane in crystalline and amorphous materials might be likened to the difference between a battalion of soldiers at attention and a crowd of people standing in a field to watch a spectacle.

The study of crystal structure was once of interest only to mineralogists. However, its paramount importance in revealing the nature of solid substances has since become evident to scientists in almost every field. The first use of X-ray diffraction by von Laue early in the 20th century, and the subsequent research into the nature of crystals, awakened research scientists to the fact that in such research lay the answers to many of their questions. In fact, studies that began on crystals led directly to the study of the atoms themselves, which has opened many new fields, including, of course, atomic energy.

The reason that we, concerned as we are with the practical uses of a knowledge of gemstones, bother with a brief survey of the nature of crystals will soon become clear. It has been found that a direct relationship exists between the structure and the important properties that lend beauty and durability to a gemstone. In addition, these properties are important in cutting and vital to the identification of gem materials. Since the crystal shapes in which gemstones often occur determine the style in which they must be cut to yield maximum weight and beauty, the cutter must know crystals to estimate how much weight he can obtain from a parcel of rough stones to bid on it intelligently. He must also know enough about the properties of the stone to be able to cut it to maximum advantage in terms of the ultimate beauty the rough can yield. To make such estimates he must have a thorough knowledge not only of the crystals but of crystal structures of gemstones. A study of the various colored stones shows that the rough crystal shape and vital differences of color with direction require that certain gemstones such as ruby, emerald and alexandrite be cut in certain specific relationships to the rough crystal directions. Failure to do so means a great loss in beauty and value. Unfortunately, many of the stones seen in the trade have been cut incorrectly, with a resultant loss in per carat value. The competent gemologist is often able to correct such an error and enhance the stone's value by having it recut properly.

IV. THE FORMATION OF CRYSTALS.

Everything about us--all of the substances of the earth, sea and air--is composed of atoms of one or more of the 92 natural elements. Of these, only relatively few are commonly encountered, since oxygen and silicon between them account for over 74% of the weight of the rocks in the earth's crust. Only eight elements are present in quantities equaling as much as 1% of the surface of the earth as we know it. In addition to oxygen and silicon, the remaining six are aluminum, iron, magnesium, calcium, sodium and potassium. Only a few others make up as much as 1/10 of 1% of the earth's crust. These include hydrogen, titanium, chlorine and phosphorus. Such seemingly common metals as copper, lead and zinc together equal only 16/1000 of 1% of the earth's crust. All of the elements, with the exception of the so-called noble gases (argon, neon, krypton, etc.), which are inert chemically, have affinities for other elements in various degrees.

When compounds are dissolved and taken into solution, their components are said to IONIZE; i.e., assume positive or negative charges. Ions may be made up of single elements or groups of them, and may have single charges or two or more. If a very insoluble material is formed when oppositely charged ions meet, it will be deposited immediately. As a hot solution or molten rock cools, the minerals that can form from its components are usually deposited in order from the least soluble to the most soluble. Since the electrical charges on the ions are directional in nature, the atoms making up this material that is starting to form take regular places in the structure. A molten mass of rock behaves in the same manner as a water solution, so the same situation can take place with the growth of a crystal in a cooling molten mass. Thus when molten masses are congealing slowly or when liquids are evaporating, the atoms of which they are composed may arrange themselves in a definite pattern one to another and form solids known as CRYSTALS or CRYSTALLINE MATERIAL. For example, as the water vapor in air cools to the freezing point, its atoms accumulate in a regular pattern to form the ice crystals we see on windows. The atoms composing water vapor in air arrange themselves into a great variety of six-sided shapes we know as snowflakes. Salt on the beaches crystallizes as sea water evaporates. However, if the formation of the solid is too hurried, such as the rapid cooling of molten glass, the atoms may not have sufficient time to arrange themselves in an orderly manner and the result will be an amorphous structure.

The affinity of atoms of one element for atoms of other elements often results in a growing process, although not in the same sense that plants and animals grow. Crystal growth may be likened to the growth of a mass of tiny iron filings attracted to a magnet. It can better be described as the attraction of like atoms forming layer upon layer from the center outward producing a definite geometric form. This growth results in a crystal form with faces so symmetrically placed and so smooth and highly reflective that it creates doubt on the part of an inexperienced observer that they have not been fashioned by man. Crystals are among the most unusual objects in nature, since they do seem to have this growth characteristic even though they are inorganic and have no life. Each crystal attracts the same kind of materials of which it is composed and arranges them with a fantastic accuracy in specific positions and holds or locks each atom into place. Almost every compound that forms in nature takes on a crystal structure as it accumulates. It is rare to encounter inorganic materials in nature without a definite internal structure, such as glass and opal. They are the exceptions rather than the rule.

Perhaps one may understand more thoroughly what is meant by this orderly internal arrangement, or crystal structure, from the sketches of the SPACE LATTICES of diamond (Figure 1) and fluorite (Figure 2).

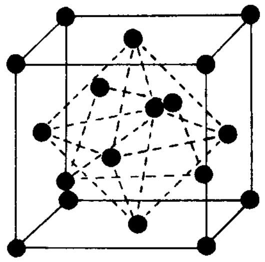


FIGURE 1.

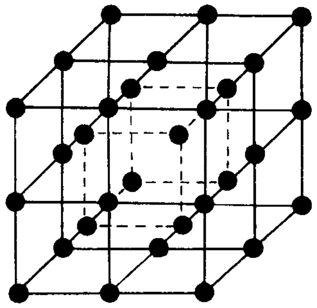


FIGURE 2.

These are called space lattices because they indicate the three-dimensional arrangement of the atoms in a UNIT CELL (the smallest unit of a lattice that illustrates all of its characteristic geometrical properties and constituents). The tiny particles shown in these sections must be imagined to have been magnified millions of times and not to be in actual close contact with one another. The lines in the sketches connecting the atoms are imaginary and are included merely to indicate the "pattern" made by the atoms. One must imagine a piece of mineral to be composed of billions of similar sections.

From this short description, one can be expected only to visualize what is meant by crystal structure in general. Space lattices are not merely theoretical; they are based on actual X-ray photographs of the Laue type, which have revealed the internal arrangement of most minerals.

The physical properties of a mineral, such as cleavage, hardness and toughness, depend on the internal structure. These properties vary as the arrangement of the internal particles vary.

V. THE EXTERNAL FORM OF CRYSTALS.

A regular internal structure means that if growth is not confined by other solids, definite geometrical forms bounded by plane (flat) surfaces, or FACES, will result. These crystal forms reflect the internal arrangement of the particles that comprise the material. Crystalline material that has assumed a definite geometric form is known as a CRYSTAL. Such crystals may vary from scores of feet in length to very small particles. They may be so small that in crystalline aggregates they can only be recognized as individual crystals by a powerful microscope. Beryl crystals have been known to weigh more than a ton, and spodumene crystals have been found that weighed as much as 37 tons and measured 47 feet in length. These, of course, were not of gem quality.

VI. PLANES OF ATOMS AND CRYSTAL FACES.

All crystalline substances grow or enlarge gradually by the orderly deposition of layers, or PLANES, of atoms, the distances between which are, of course, different in various substances. It is easier to understand crystal growth and crystal forms by thinking of the crystal faces as corresponding to such planes of atoms, with the atoms in each layer arranged in a definite pattern. Each mineral species has a characteristic pattern of its own that results in characteristic external forms, or crystal shapes. Sometimes material with the same chemical composition may assume different atomic arrangements, or patterns. In this event, each is a separate and distinct mineral. For example, DIAMOND and GRAPHITE are both wholly composed of CARBON, yet their properties are amazingly different because of the differences in crystal structure.

VII. CRYSTAL, OR CRYSTALLINE, MATERIAL.

Often a crystalline structure does not result in a definite geometric external form that is recognizable to the eye. Such material, although having an internal crystalline structure, appears to the unaided eye as a more or less shapeless mass and is known as crystalline material with a MASSIVE form. This is most commonly encountered when the position in which the mineral grew was confined by other growing crystals.

VIII. GLASS.

It is obvious that, scientifically, the term crystal means WITH orderly internal structure, whereas the term glass means WITHOUT orderly internal structure. It is correct to refer to an amethyst necklace as being crystal, but a manufactured glass imitation of amethyst is NOT crystal. Also, a manufactured glass replica of a rough diamond crystal is not crystal. It is clear from this that fine lead glassware is incorrectly called "crystal." Certain naturally occurring substances possessing neither orderly arrangement of atoms nor constant chemical formulae, such as obsidian, are known as NATURAL GLASSES.

IX. OUTWARD APPEARANCE OF CRYSTALLINE MATERIAL.

Since crystalline materials occur in nature in several different forms, it is desirable to use a number of different terms to describe such materials, based on their appearance to the unaided eye.

A. Crystals.

Crystals are substances that possess a crystal structure and are wholly or partly bounded by natural, plane surfaces.

B. Twin Crystals.

Sometimes two crystals, or two parts of the same crystal, are joined together along a common axis, or plane. Such a formation is called a TWIN CRYSTAL.

C. Crystal Aggregates, or Groups.

A number of crystals sometimes grow together. Each crystal in the group is large enough to be seen easily. A group of such crystals thus grown together is known as a CRYSTAL AGGREGATE or a CRYSTAL GROUP.

D. Crystalline Aggregates.

Crystalline aggregates are composed of many very small individual crystals, often too small to be seen by the unaided eye. Metals such as gold and silver in their native state, as alloys, and even when rolled and shaped for use in jewelry, are CRYSTALLINE AGGREGATES.

E. Cryptocrystalline Aggregates.

These are aggregates of crystals so tiny that even high magnification fails to resolve them. Their presence is proved by their effect on polarized light. Agate, carnelian and other varieties of chalcedony are examples.

X. DISTORTED AND DEFORMED CRYSTALS AND PSEUDOMORPHS.

A. Distorted Crystals.

These seldom approach perfection in their shapes but are more or less distorted, since their faces have not all enjoyed an exactly equal and perfect development. Probably faces develop unequally due to their relationship to the source of supply of the solutions carrying the atoms of which they are composed. Growing in confined spaces, as most crystals do, some faces, or sides, are likely to grow faster than others. Such crystals may appear to be drawn out, shortened or flattened, but the corresponding angles between faces are CONSTANT.

B. Deformed Crystals.

These have been bent and twisted out of their normal shape, usually by some later deforming force, so that the corresponding angles between faces may DIFFER WIDELY. This, however, is not a common occurrence.

C. Pseudomorphs (from PSEUDO, meaning FALSE, and MORPH, meaning FORM).

After the original growth, if the chemical composition or the structure of a crystal becomes altered without modifying or destroying its original faces, the result is a crystal whose faces are unchanged but whose internal structure has become that of an entirely different mineral. The resulting crystal is known as a PSEUDOMORPH (pronounced SUE-doe-morf). Tiger's-eye is an excellent example. In this mineral the original fibers, consisting of monoclinic crystals of crocidolite (pronounced kro-SID-oh-lite), or blue asbestos, have been replaced by minute grains of quartz that, in mass, have retained the original external form of the crocidolite but each of which has assumed the internal crystal structure for quartz.

XI. CRYSTAL AXES.

To describe a crystal form it is necessary to visualize the existence of certain fixed lines of reference, similar to the imaginary line, or axis, from the north to the south pole about which the earth rotates. In an ideal crystal form these lines are of definite length in relation to each other, extend in certain definite directions, and intersect in the middle of the crystal at a point called the ORIGIN. Such imaginary lines are called CRYSTAL AXES (the plural of axis). There must be at least three axes to describe a crystal, and in one case four are necessary. These are indicated in the accompanying plate entitled "Models of the Six Crystal Systems."

XII. CRYSTAL SYSTEMS.

For convenience of study and reference, crystals are divided into six great systems, described by the comparative length and angular relation of their crystallographic axes.

(1) Cubic (or Isometric) System.

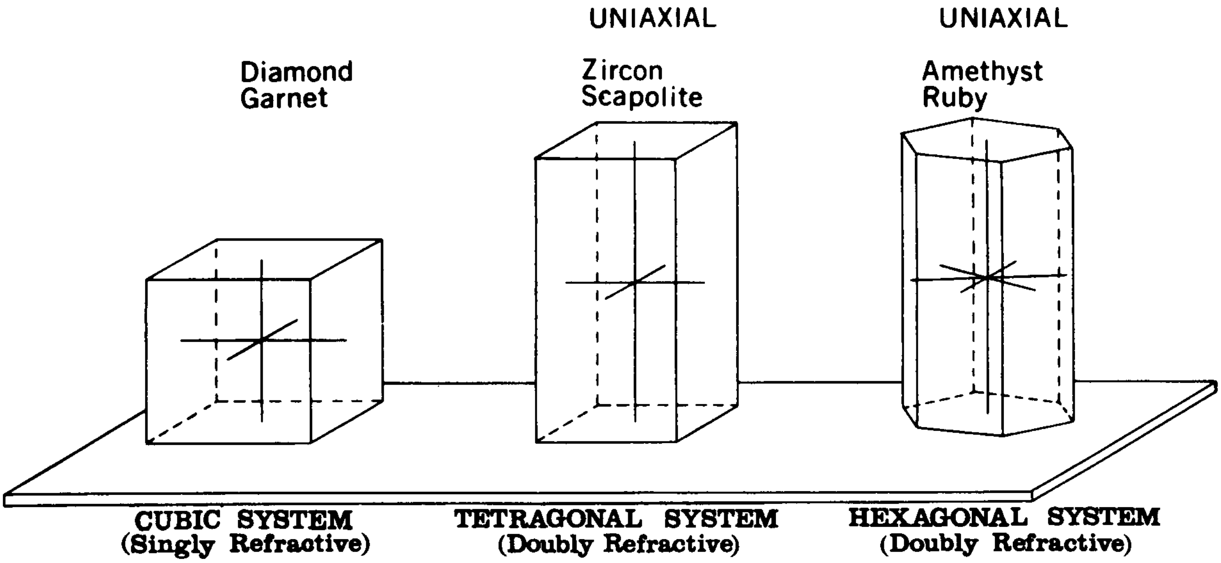
A mineral is placed in the cubic system if it can be described by three axes of equal length at right angles to one another. In a cube, if axes were passed from the center of each face to the center of the opposite face, the axes would be equal in length and at right angles to one another. Diamond, spinel and garnet crystallize in the cubic system.

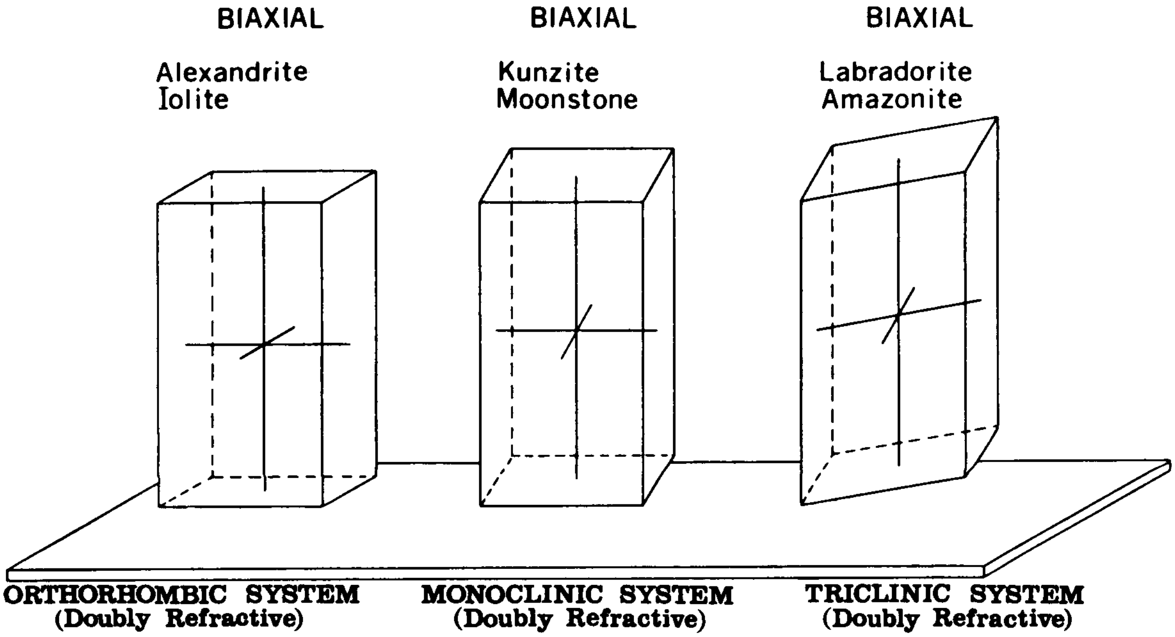
(2) Hexagonal System (pronounced hex-AG-uh-nul).

Hexagonal crystals have four axes, three of which are equal in length and intersect at 60° angles. The fourth is perpendicular to these and longer or shorter than the three previously described axes. Ruby, sapphire, emerald and aquamarine crystallize in this system.

(3) Tetragonal System (pronounced teh-TRAG-uh-nul).

MODELS OF THE SIX CRYSTAL SYSTEMS





The tetragonal system is one in which there are three axes that intersect at right angles, but only two of which are equal in length, the third being either longer or shorter than the first two. The basic form resembles a cube elongated in one direction. Zircon crystallizes in this system.

(4) Orthorhombic System (pronounced or-tho-ROM-bik).

This system is characterized by three mutually perpendicular axes of unequal length. The basic form resembles a box with length, width and depth unequal. Topaz crystallizes in this system.

(5) Monoclinic System (pronounced mon-oh-KLIN-ik).

The three axes in this system are unequal, two intersect at an angle other than at right angles, and a third is perpendicular to these two. The basic form can be visualized as a box deformed so that the top is still rectangular but one side view is a parallelogram. Jadeite and nephrite crystallize in this system.

(6) Triclinic System (pronounced try-KLIN-ik).

The triclinic system is the one of least symmetry. It is described by three axes, all unequal in length, and inclined to one another at angles other than 90°. A basic form would resemble a box deformed so that all sides are parallelograms. Labradorite and microcline feldspars crystallize in this system.

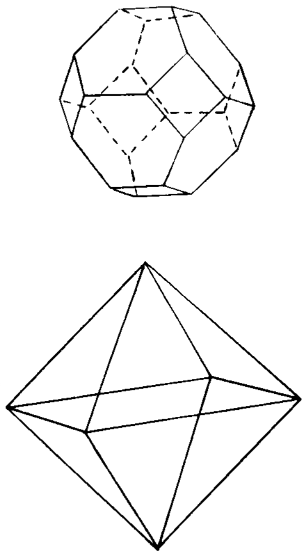
XIII. FORMS WITHIN CRYSTAL SYSTEMS.

Within each crystal system there are many different shapes that crystals can take; each basic shape is called a CRYSTAL FORM. The form or combination of forms most commonly taken by crystals of a given gem mineral is known as the HABIT of that mineral. For example, the habit of garnet is the DODECAHEDRON (pronounced doe-dek-uh-HEE-drun); of zircon, a prism modified by a pointed form called a BIPYRAMID, etc. (see accompanying plate entitled "Examples of Crystal Forms"). For reasons related to the conditions during growth, crystals of the same mineral may take different forms or combinations of forms. For example, ruby and sapphire, varieties of the same gem species, usually occur in crystals with different shapes.

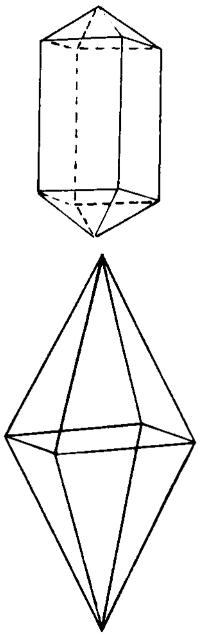
XIV. MINERALS AND ROCKS.

A mineral was defined as a naturally occuring inorganic product with a characteristic chemical composition and usually a crystal structure. Usually, rocks are made up of aggregates of one or more minerals, but they may be composed of or include either natural glasses or organic

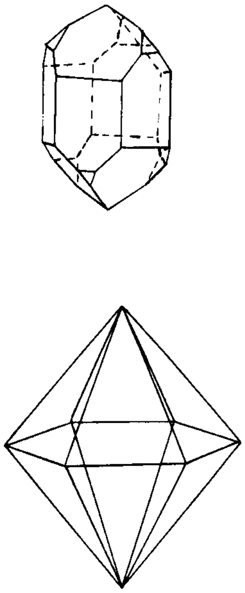
EXAMPLES OF CRYSTAL FORMS



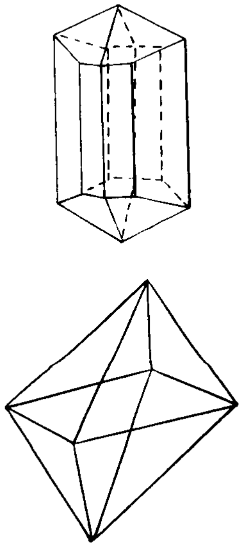
Cubic (or Isometric) System



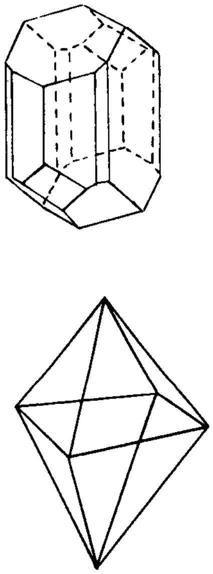
Tetragonal System



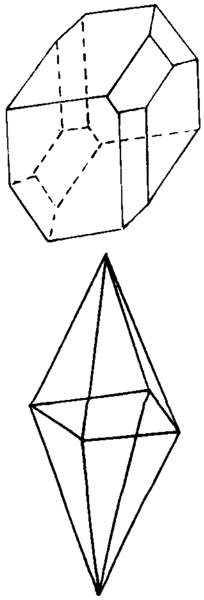
Hexagonal System



Orthorhombic System



Monoclinic System



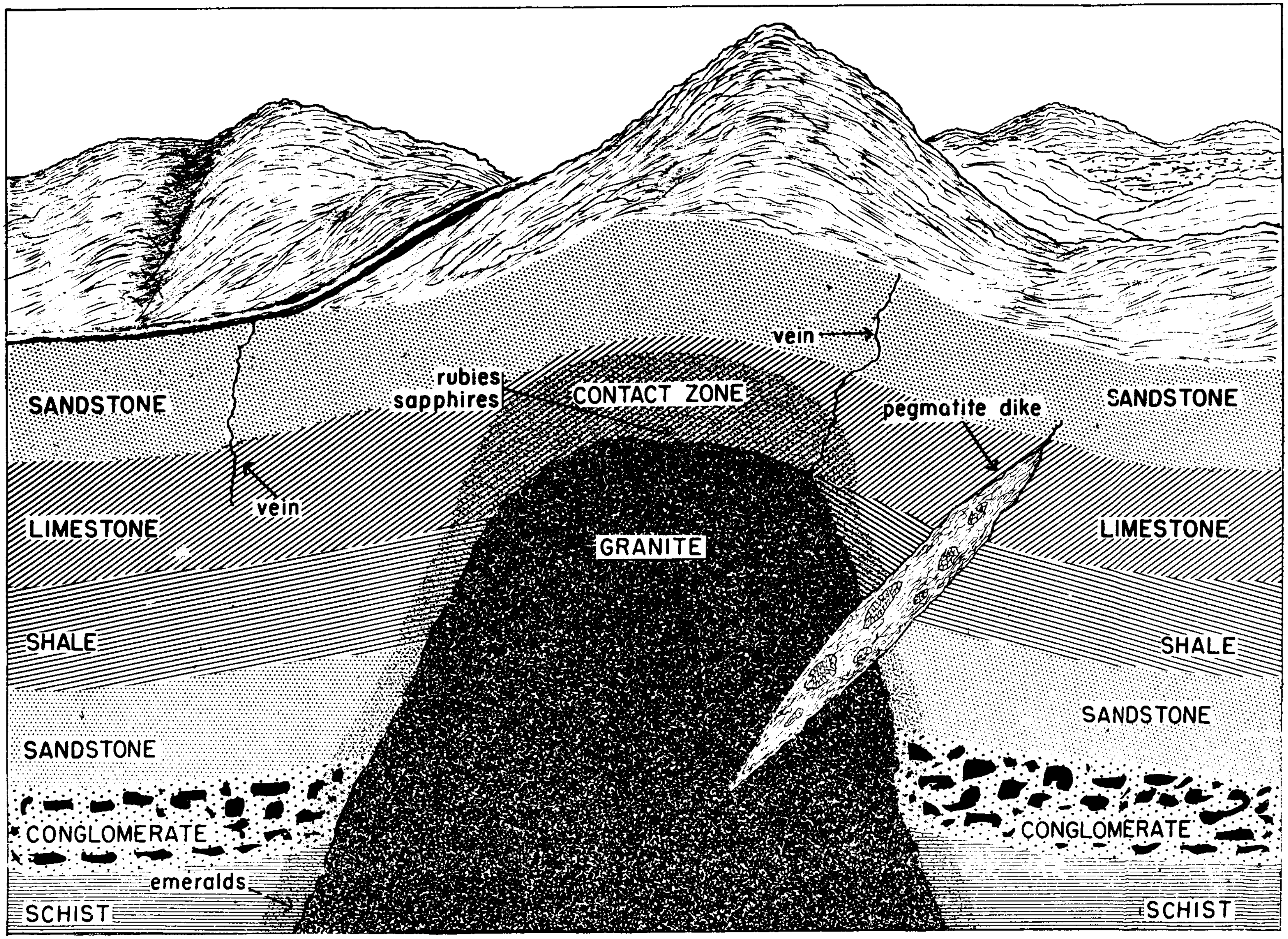
Triclinic System

materials such as coal. They are distinguished further by the fact that they make up a significant portion of the earth's crust. There are three major rock types, based on the method by which they formed.

A. Igneous Rocks.

Igneous rocks (pronounced IG-nee-us) are those that formed as the result of the cooling of molten rock masses, which are known as MAGMAS. What causes segments of the earth's crust at depth to melt has been the subject of speculation among scientists for hundreds of years. Probably the most widely accepted theory for its cause today is that energy supplied by radioactivity, added to the high existing temperatures and pressures prevailing at depth, triggers the melting action. Such molten rock bodies may be very limited in extent or extend for a thousand miles or more. The core of the Sierra Nevada Mountains between California and Nevada, which has a total length of 1100 miles, was formed by the cooling of an enormous molten mass, yielding an igneous rock akin to granite. If molten rock cools and solidifies slowly at depth, it will be coarsely crystalline. Rapid cooling may produce a natural glass such as obsidian, a porous rock such as pumice, or a very minutely crystalline rock such as lava (usually known to the mineralogist as basalt). Examples of coarsely crystalline igneous rocks are granite and the slightly less coarsely grained kimberlite (or blueground), the host rock of diamonds.

To the colored-stone man, the igneous rock of greatest interest is the PEGMATITE DIKE. A dike is a lens-shaped body of igneous rock. A pegmatite dike is a type formed late in the cooling and solidifying process of a magma that has a composition similar to that of a granite. As such a mass cools at depth, many of the components start to crystallize. The more volatile constituents remain liquid for a longer period and accumulate in cracks both in the hardening mass and in the surrounding rocks. Because the mass has been molten for a long period by this stage, the temperature in the hardening mass and surrounding rocks has become very even. Further cooling will be slow. In addition, the remaining liquid is very volatile, so the conditions are ideal for the growth of large crystals of fine quality. The fluidity of the volatile end products permits atoms to move about freely, so that even those present in minute quantities have an opportunity to reach other like atoms and form crystals. Thus certain very rare elements may form crystals of significant size. Although beryllium is a rare element, large beryl crystals are sometimes formed in pegmatite dikes. Other gem minerals found in pegmatite dikes include topaz, tourmaline, kunzite, moonstone and chrysoberyl, as well as many rare gem minerals such as euclase and apatite.



GEOLOGICAL SITUATIONS IN WHICH GEMSTONES MAY FORM

Another manner in which gems may be formed in connection with igneous activity is that in which solutions emanating from the magma deposit minerals in crevices in surrounding rocks, often at considerable distances from their point of origin. The cracks filled in this manner are called VEINS. The same term is applied to similar crevices filled by deposition from circulating subsurface cool waters just below the surface. An example of the first type is amethyst or emerald, and of the second, turquois, malachite or quartz. Nodular rocks that are hollow and lined with crystals of quartz or other minerals are called GEODES (pronounced GEE-odes). The crystals are usually deposited by relatively cool solutions.

B. Sedimentary Rocks.

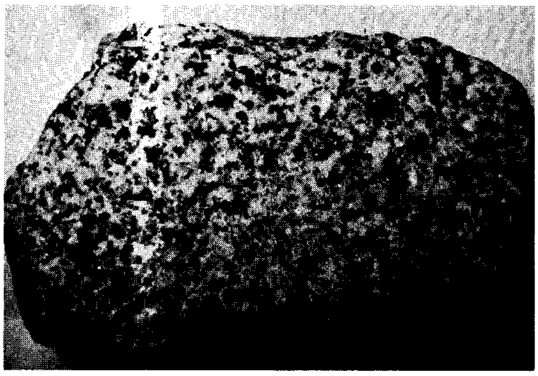
Weathering agents at the earth's surface are perpetually active in decomposing rocks. The action of ground water, frost, chemicals, plants, streams, wind and bodies of water break up the rock. Streams, wind and other agents carry off the fragments to be redeposited elsewhere. These are called SECONDARY DEPOSITS, in contrast to the igneous rocks, which are regarded as PRIMARY DEPOSITS. Concentration of the heavier minerals by streams in river gravels provides the most important gem sources among the sediments. Such deposits are termed PLACER or ALLUVIAL. Almost every gem mineral that is reasonably durable is found in alluvial deposits. Thus, with the exception of opal, turquois, malachite, kunzite and a few other gemstones, most gem minerals are produced in important quantities from gravels.

The important sedimentary rocks in order of decreasing grain size are conglomerate, sandstone, shale and limestone. Since conglomerate represents gravel that has been consolidated into rock, some gem production comes from conglomerates. With this minor exception, sedimentary rocks of themselves are of minor importance to the gemologist. However, many vein-type deposits are found in sediments; e.g., opal and turquois.

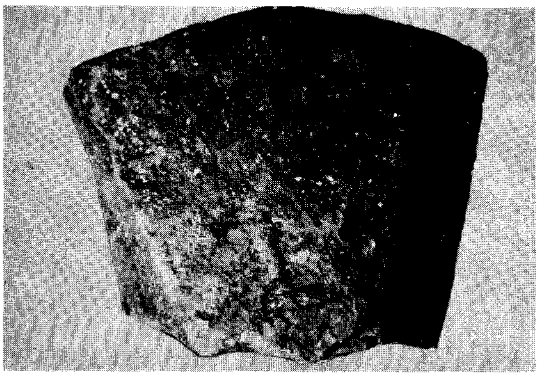
C. Metamorphic Rocks.

The derivation of the word METAMORPHIC (pronounced met-uh-MOR-fik) explains its meaning. It is from the Greek words META (meaning CHANGE) and MORPH (meaning FORM). Metamorphic rocks are those that have been changed from their previous form by agencies such as heat, pressure, and/or action of nearby molten masses. The major type, REGIONAL METAMORPHISM, is of limited interest to the gemologist, for little of gem quality results. In this type, the heat and pressure generated by tens of thousands of feet of overlying rocks, or that which accompanies the folding of rocks during mountain-building activities within the

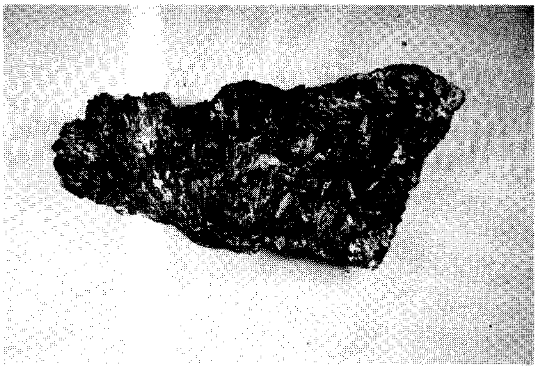
ROCKS



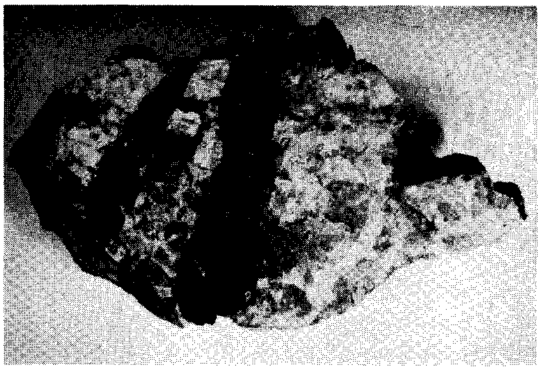
Igneous Rock - slow cooling - showing the granular aggregate structure.



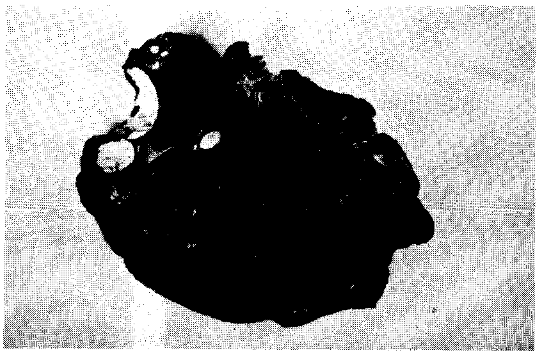
Sedimentary Rock: Fossil in a stratified rock.



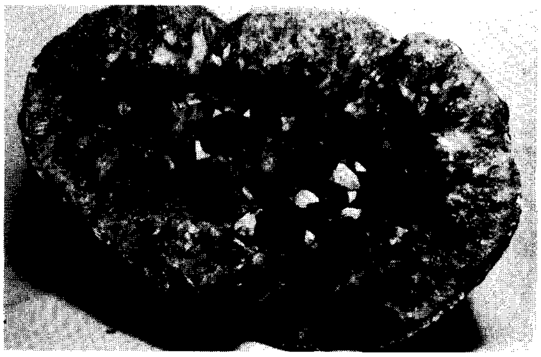
Metamorphic Rock: A schist with a fibrous appearance.



Pegmatite - showing characteristically large crystals.



Obsidian: Natural glass - a result of rapid cooling of molten rock.



Geode - Open Quartz crystals lining the cavity.

crust, cause drastic changes. Sandstone becomes quartzite, shale becomes slate, limestone becomes marble, and platy rocks such as schists form. During such processes crystals often grow in solid rock! Although garnets form under these conditions, they are seldom of gem quality.

The type of metamorphism of prime importance to the gemologist is that called CONTACT METAMORPHISM. In this type, existing rocks are "cooked" by the intrusion of a nearby mass of molten rock. The combination of the resulting increase in temperature and the solutions traveling out from the magma often cause the original rock to recrystallize. In the process, impurities from the pre-existing rock often become concentrated and form new minerals. When impure limestones recrystallize under these conditions, corundum (ruby and sapphire) may form, as well as spinel and other gem minerals. Mogok, Burma, by far the most important single colored-stone locality in the world, is such a deposit.

XV. GENERAL COMMENTS.

The background of geology and mineralogy relating to the formation of gemstones contained in this assignment suffices for the student concerned primarily with gem identification, appraisal and sales. However, these are subjects that many people find fascinating. After you have completed this course, you may want to explore the field further. If so, your instructor will be happy to recommend a number of books that are likely to be available in your local library.